CUETHINK

CueThinkEF+ Significantly Increases Students' Problem Solving Performance

The project aimed to support students-particularly those from historically underserved backgrounds-develop mathematical problem solving skills by explicitly attending to and supporting executive functioning.

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EXECUTIVE SUMMARY

In 2020, CueThink was awarded a contract from the Advanced Education Research and Development Fund (AERDF) to extend its core application to support a broader range of learners. The project aimed to support students–particularly those from historically underserved backgrounds–develop mathematical problem solving skills by explicitly attending to and supporting executive functioning.

This paper shares key findings from year 2 of the project, which occurred during the 2021-2022 academic year. Within this, the two main research questions were:

1. Does combining executive function, metacognition, anxiety, and belief supports predict increases in students' mathematical problem-solving beyond the unique contributions of each individual component?
2. Does the use of CueThinkEF+ and the associated professional learning (PL) correspond with increases in mathematical problem solving?

In answering these questions, we partnered with a West Coast school district and used a quasi-experimental research design that consisted of 1 school in the intervention group and 2 schools in the control group. From these schools, an initial sample of 222 students in the control group and 236 students in the intervention group participated in the study.

Teachers in the intervention group were provided with six professional learning sessions and were given access to CueThinkEF+, which included additional features that were co-designed by teachers and students. Students created solutions to problems within the application approximately 5-10 times over the course of the school year.

Research Question 1:
Although the data showed that numerous factors are related to student success in problem solving, **student beliefs and executive functions appear to be particularly important.**

Specifically, the data highlighted the importance of supporting students in developing positive beliefs such as growth mindsets (the belief that one can improve their performance through hard work) and self-efficacy (the belief that one has the ability to accomplish a goal).

Additionally, working memory was significantly related to problem solving success, suggesting that students may benefit from being explicitly taught strategies that scaffold working memory. These strategies may include breaking the problem solving process down into chunks (e.g., explore, plan, solve, reflect), providing sentence starters to communicate thinking, providing alternative modalities for accessing information (e.g., visual and or auditory, in addition to text), as well as allowing multiple ways for students to express their understanding (e.g. through visuals such as manipulatives or models).

Research Question 2:
Pre- and post-tests on problem solving found that **students in the intervention group significantly improved their problem solving performance when compared to** students in the control

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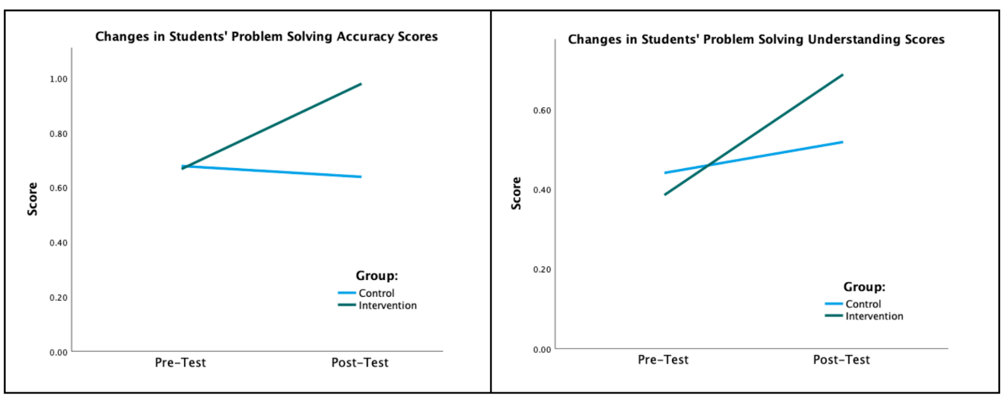
group. These results held for both the total number of questions that students answered correctly (accuracy) as well as the amount of correct mathematical thinking that their work displayed (understanding). In addition, improvement on the problem solving test was associated with higher usage of CueThinkEF+.

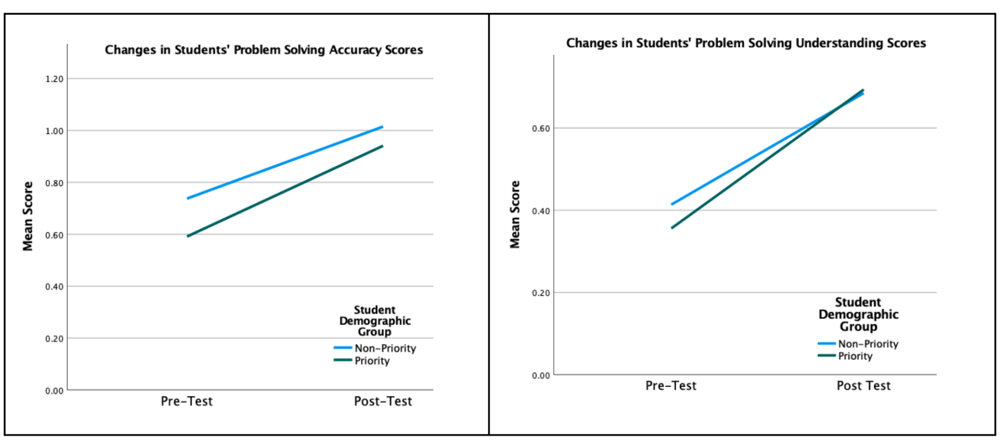
These results suggest that CueThinkEF+ played a key role in improving students' problem solving performance. Moreover, the results were not only statistically significant, but also showed medium to large effect sizes, meaning that the impact on students was substantial. This highlights the significant positive impact the use of CueThinkEF+ had on student problem solving success. These results are visually represented in Figures 1 and 2, shown below.

In addition to improving students' problem solving performance overall, the data was analyzed based on scores for priority (students identifying as Black, LatinX, and/or Native American) and non-priority groups of students. Promisingly, the initial differences in scores seen at the beginning of the study–likely as a result of systemic opportunity gaps–**closed or were eliminated over the course of the study** (see Figures 3 and 4).

Taken together, these results suggest that **coupling the use of CueThinkEF+ with professional learning for teachers may result in significant gains in student problem solving performance and may help close gaps in scores between groups of students.**



Figures 1 and 2: Changes in problem solving accuracy and understanding over time by group



Figures 3 and 4: Changes in problem solving accuracy and understanding over time by demographic group

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CueThinkEF+ strengthens students' EF, metacognition, and positive math beliefs during collaborative math problem solving.

1

Creates access for all
The problem solving process is broken down into phases to give all students access to challenging math that strengthens their executive function skills.

2

Promotes metacognition
Students choose from a variety of embedded executive function scaffolds while solving a problem to promote metacognition and reflection. Student thinking is captured 'in the moment' using a digital whiteboard and voice recording.

3

Develops positive math beliefs
Every student's unique solution pathway is showcased to foster a sense of belonging. Students write questions and comments about peers' work to engage in math discourse and see themselves as mathematicians.

Providing all students opportunities to thrive in math.

CueThinkEF+ Significantly Increases Students' Problem Solving Performance

RESEARCH REPORT

It has long been understood that supporting students in developing as problem solvers is a key goal in K-12 mathematics courses (e.g., NCTM, 1989, 2014). Unfortunately, despite numerous studies exploring various instructional interventions such as heuristic training (Schoenfeld, 1979), metacognitive training (Tan & Limjap, 2018), and schema-based instruction (e.g., Powell & Fuchs, 2018), mixed results have meant that it remains unclear how best to support students in developing the ability to problem solve (Lester & Cai, 2016).

One potential reason for these mixed results may be that mathematical problem solving is intrinsically tied to multiple factors such as heuristic thinking, metacognition, student beliefs (see Chapman, 2015), and executive function (EF; Zelazo & Carlson, 2020). EF refers to the cognitive abilities needed for goal-directed behavior, including holding and manipulating information in the moment (working memory), forestalling impulses (inhibitory control), and switching between thoughts or perspectives (cognitive flexibility; Miyake & Friedman, 2012). Development of efficient EF skills may in fact be an underlying, common component to all of these skills. Consequently, the current study sought to tackle these challenges by exploring which factors are related to problem solving success and then explicitly targeting and scaffolding for multiple factors such as executive function, metacognition, and student beliefs. Within this, we posed the following research questions:

1. Does the impact of combining supports targeting students' executive function, metacognition, anxiety, beliefs, and problem-solving predict increases in students' mathematical problem-solving beyond the unique contributions of each individual component?
2. Does the use of CueThinkEF+ and the associated professional learning (PL) correspond with increases in mathematical problem solving?

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Overview of the Methods

The study was conducted within a west-coast state during the 2021-2022 school year. Three schools participated in the study for the entire duration of the year with 1 school being assigned to the intervention group and 2 schools to the control group. All participating students completed pre- and post-tests which included measures of math anxiety (Carey, 2017), EFs (Adaptive Cognitive Evaluation Explorer, 2021), metacognitive awareness (Sperling et al., 2002), beliefs on problem solving (Kloosterman & Stage, 1992), and iReady scores (see Curriculum Associates, 2022).

In addition, a problem solving measure for each grade was developed using problems that were developed by Illustrative Mathematics (IM) and that were aligned to the participating districts' pacing guide with 1 problem being related to a standard for each trimester. Within this, standards were chosen that were deemed to be of high-importance by the district to ensure that all teachers in both the intervention and control groups would adequately address them during the academic year. However, given that CueThinkEF+ is designed to impact the broader construct of problem solving and not just specific standards, the product was not designed or modified to expressly address the assessed problems or standards.

For each measure, a scoring protocol was developed that detailed accepted correct answers as well as the mathematical understandings that may be demonstrated within student work. Consequently, each question was given both a correctness/accuracy score as well as an understanding score that was based on the percentage of understandings that each student demonstrated. Each scoring protocol was discussed and refined until the Fleiss' Kappa for each measure was sufficiently high.

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STUDY FINDINGS

Research Question 1

To answer the first research question, pre-test data was used from sixth-grade students who completed all of the measures. Across groups, this resulted in a total sample of 118 students. After screening for the requisite statistical assumptions, a series of multiple regression analyses (ordinary least squares standard regression models) were run using various pre-test scores to predict performance on the problem solving measure. Multiple regression analysis is used to analyze the relationship between a single dependent variable (e.g., math scores) and many (multiple) independent variables (e.g., EF, metacognition, beliefs, etc.). This allows for an analysis of how well the independent variables relate to, or predict, the outcome (dependent) variable. This analysis was repeated using both the problem solving measure correctness and understanding scores.

For the correctness score, four unique variables remained in the final model [$F(13, 105) = 2.99$, $p = .001$, $R2 = .235$]. The four variables were mathematical beliefs, a filter measure of executive functions, iReady scores, and a question measuring the extent to which students reported having opportunities to reflect on their learning in math class.

For the understandings score, three unique variables remained in the final model [$F(13, 105) = 3.03$, $p = .001$, $R2 = .273$]. The three variables were mathematical beliefs, a filter measure of executive functions, and an executive functions measure that assessed a combination of working memory and inhibition.

In addition to the statistical significance p-value score (a measure of the probability that the results are due to chance with the results above suggesting that there is only a 0.1% probably that the results noted above are due to chance) a regression analysis outputs a R2 value, which is an indication of how well the statistical model describes our observations (i.e., our data). A value of 1 would indicate a perfect fit. The R2 value also represents how much of the variance (difference between observed and predicted values) can be explained by the regression model. So in our models, the independent variables explain roughly a quarter of the variance for the correctness (23.5%) and understanding (27.3%) problem solving scores. These results suggest that our hypothesis was correct in that problem solving scores were best predicted by the combination of several factors. Specifically, components of executive function (e.g., inhibition) and student beliefs about mathematics were significant components in both models, suggesting that these factors are critical to consider when supporting students with improving their mathematical problem solving abilities.

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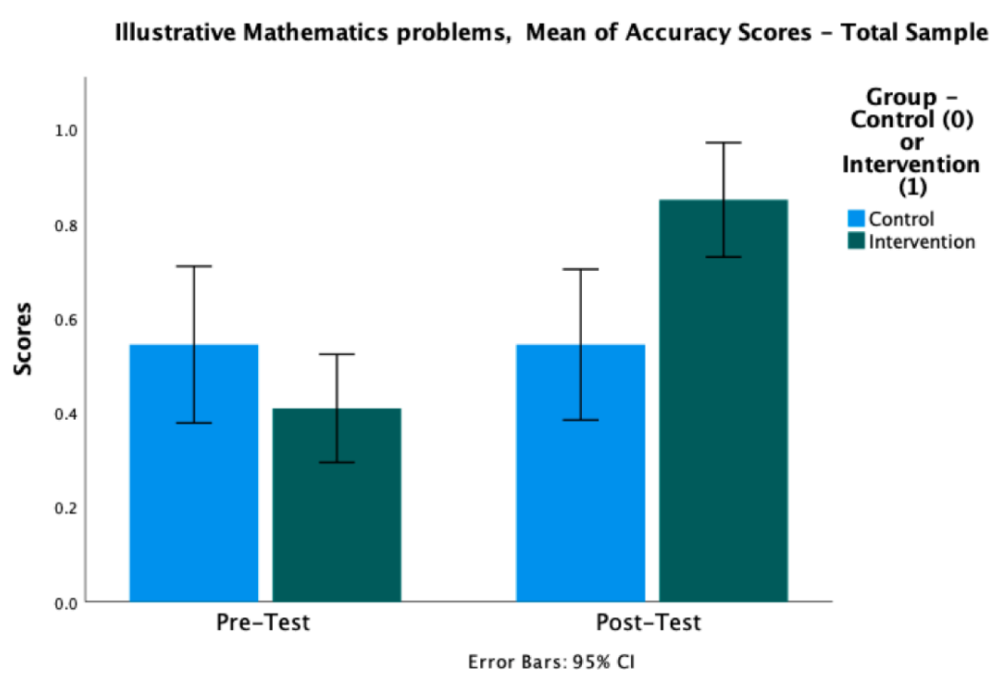
Research Question 2

To answer the second research question, the problem solving measures described above were administered at the beginning and end of the school year. The number of students who took both tests being summarized in Table 1 below.

	6th Grade	7th Grade	8th Grade	Total
Intervention	98	94	2	194
Control	56	45	0	101
Total	154	139	2	295

Pre- and post-test scores were analyzed using analyses of covariance (ANCOVA's) to account for any pre-existing differences between the groups. Total sample and grade level specific analyses were run for each of the understanding and correctness scores. Although only the 7th grade analyses are detailed here, it is worth noting that every analysis showed statistically significant growth for the intervention group when compared to the control group with the sole exception being the analysis of 6th grade understanding scores wherein the analysis did not reach statistical significance despite movement in the anticipated direction.

Looking first at the analysis of accuracy scores for 7th grade, the ANCOVA was statistically significant ($F = 11.684$, $df = 1$, $p < .001$) with a medium to large effect size of .079 as measured by a partial eta squared (see figure 1).



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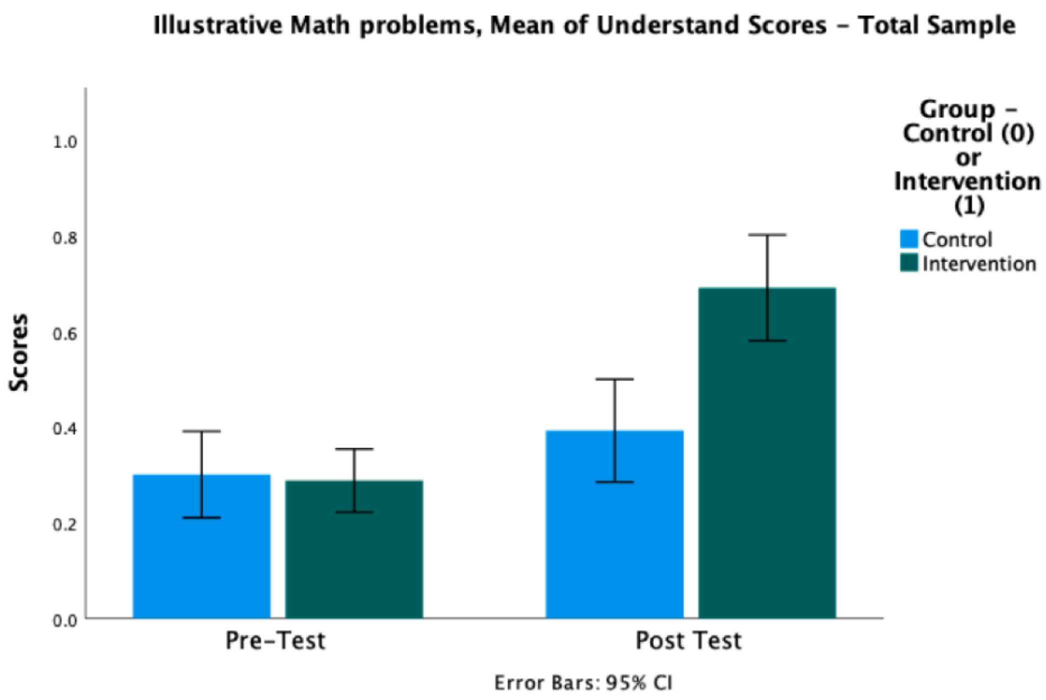
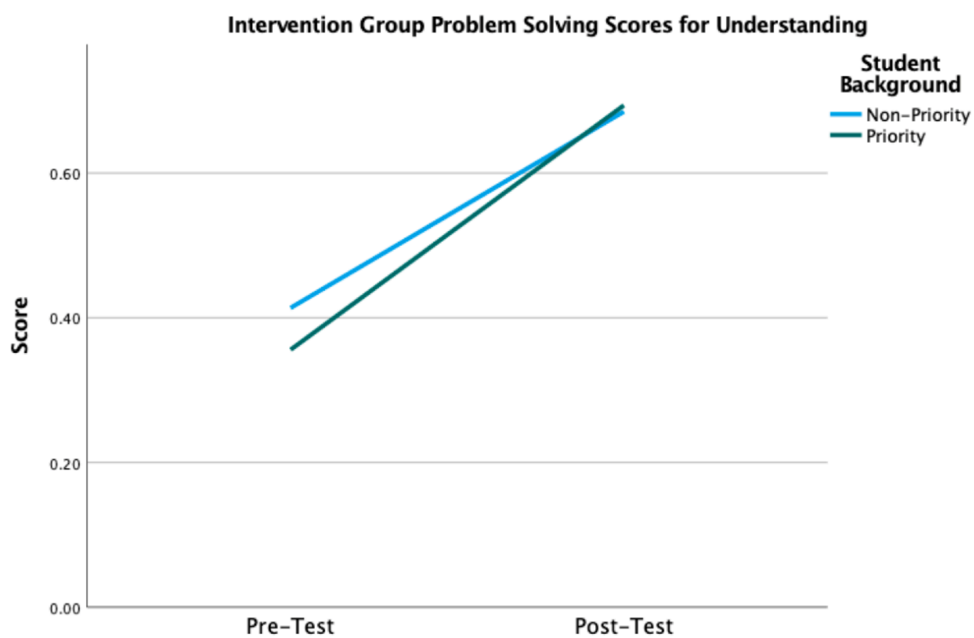
Similarly, the analysis of understanding scores for 7th grade, the ANCOVA was also statistically significant ($F = 16.624$, $df = 1$, $p < .001$) with a large effect size of .097 as measured by a partial eta squared (see figure 2).



Finally, independent-samples t-tests were used to look for differences in scores between priority and non-priority students. These tests are used to determine whether differences between groups are attributable to factors other than random chance. The analyses indicated that gaps between scores of students closed over the course of the study.



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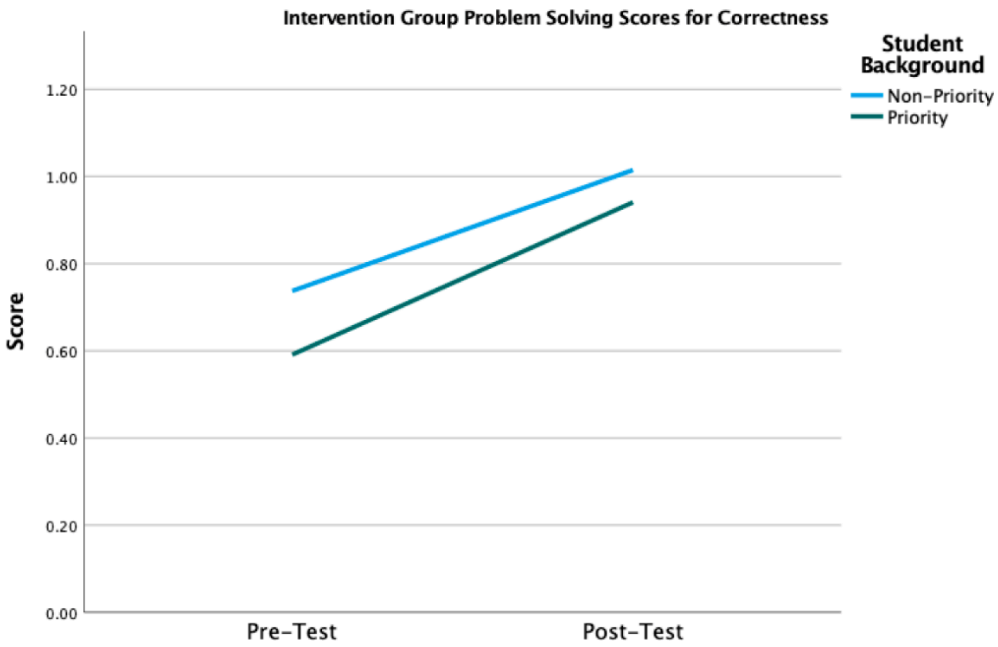

CONCLUSION

These results suggest that the **use of CueThinkEF+ along with the associated professional learning resulted in significant increases in students' mathematical problem solving abilities.** While additional research is needed to further improve student gains in problem solving by targeting additional factors associated with problem solving success (e.g., beliefs, working memory, etc.), these results are extremely promising and suggest that CueThinkEF+ is an effective tool in improving problem solving performance. Future research with the study will build on these promising findings by explicitly addressing student beliefs within the application and by supporting students in transferring in-product scaffolds to applications outside of the product.

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